AD-A038 789 RANGE COMMANDERS COUNCIL WHITE SANDS MISSILE RANGE N--ETC F/G 16/1

REAL-TIME METHODS OF INSTRUMENTATION COMBINATION AND DATA SELEC--ETC(U)

APR 77

UNCLASSIFIED RSG-314-72 NL

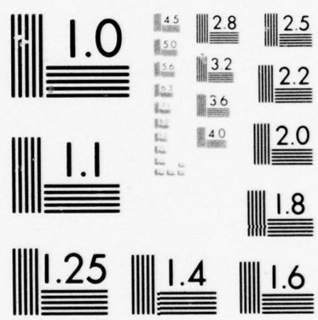
1 OF 1

AD A038789

END

DATE FILMED

5-77


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

RSG

AD A 038789

DOCUMENT 314-77

REAL-TIME METHODS OF INSTRUMENTATION COMBINATION AND DATA SELECTION FOR RANGE SAFETY CALCULATIONS

RANGE SAFETY GROUP
RANGE COMMANDERS COUNCIL

KWAJALEIN MISSILE RANGE
WHITE SANDS MISSILE RANGE
YUMA PROVING GROUND

NAVAL WEAPONS CENTER
PACIFIC MISSILE TEST CENTER
ATLANTIC FLEET WEAPONS TRAINING FACILITY
NAVAL AIR TEST CENTER

AIR FORCE EASTERN TEST RANGE
AIR FORCE FLIGHT TEST CENTER
AIR FORCE SATELLITE CONTROL FACILITY
SPACE AND MISSILE TEST CENTER
ARMAMENT DEVELOPMENT AND TEST CENTER
AIR FORCE TACTICAL FIGHTER WEAPONS CENTER

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	314-77 (14) RSG-314-72
2. GOVT ACCESSION NO.	
3. RECIPIENT'S CATALOG NUMBER	(9)
4. TITLE (*and Subtitle*)	(6) Real-Time Methods of Instrumentation Combination and Data Selection for Range Saftey Caluclations.
5. TYPE OF REPORT & PERIOD COVERED	FINAL rept.
6. PERFORMING ORG. REPORT NUMBER	none
7. AUTHOR(*s*)	Range Safety Group Range Commanders Council White Sands Missile Range, NM 88002
8. CONTRACT OR GRANT NUMBER(*s*)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Same as above (12) 60p.
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS	Secretariat Range Commanders Council (STEWS-SA-R) White Sands Missile Range, NM 88002
12. REPORT DATE	(11) Apr[redacted]77
13. NUMBER OF PAGES	56
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)	Same as 11
15. SECURITY CLASS. (*of this report*)	UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (*of this Report*)	Approved for public release.
17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)	Same as 16
18. SUPPLEMENTARY NOTES	Supersedes 314-72 782 699 (No AD Number)
19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)	Prevention of injury to personnel or damage to property, precautions taken in the preparation of a missile or vehicle launch, surveillance during flight to insure compliance with safety criteria.

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A survey of seven of the test ranges represented in the Range Safety Group (RSG) of the Range Commanders Council (RCC) was made to determine the real-time methods of selection and combination currently in use at the various ranges. This information is presented in this document to assist all ranges in determining which systems may have merit for their application and to provide some insight into future applications.

INSTRUCTIONS FOR PREPARATION OF REPORT DOCUMENTATION PAGE

RESPONSIBILITY. The controlling DoD office will be responsible for completion of the Report Documentation Page, DD Form 1473, in all technical reports prepared by or for DoD organizations.

CLASSIFICATION. Since this Report Documentation Page, DD Form 1473, is used in preparing announcements, bibliographies, and data banks, it should be unclassified if possible. If a classification is required, identify the classified items on the page by the appropriate symbol.

COMPLETION GUIDE

General. Make Blocks 1, 4, 5, 6, 7, 11, 13, 15, and 16 agree with the corresponding information on the report cover. Leave Blocks 2 and 3 blank.

Block 1. Report Number. Enter the unique alphanumeric report number shown on the cover.

Block 2. Government Accession No. Leave Blank. This space is for use by the Defense Documentation Center.

Block 3. Recipient's Catalog Number. Leave blank. This space is for the use of the report recipient to assist in future retrieval of the document.

Block 4. Title and Subtitle. Enter the title in all capital letters exactly as it appears on the publication. Titles should be unclassified whenever possible. Write out the English equivalent for Greek letters and mathematical symbols in the title *(see "Abstracting Scientific and Technical Reports of Defense-sponsored RDT/E,"AD-667 000)*. If the report has a subtitle, this subtitle should follow the main title, be separated by a comma or semicolon if appropriate, and be initially capitalized. If a publication has a title in a foreign language, translate the title into English and follow the English translation with the title in the original language. Make every effort to simplify the title before publication.

Block 5. Type of Report and Period Covered. Indicate here whether report is interim, final, etc., and, if applicable, inclusive dates of period covered, such as the life of a contract covered in a final contractor report.

Block 6. Performing Organization Report Number. Only numbers other than the official report number shown in Block 1, such as series numbers for in-house reports or a contractor/grantee number assigned by him, will be placed in this space. If no such numbers are used, leave this space blank.

Block 7. Author(s). Include corresponding information from the report cover. Give the name(s) of the author(s) in conventional order *(for example, John R. Doe or, if author prefers, J. Robert Doe)*. In addition, list the affiliation of an author if it differs from that of the performing organization.

Block 8. Contract or Grant Number(s). For a contractor or grantee report, enter the complete contract or grant number(s) under which the work reported was accomplished. Leave blank in in-house reports.

Block 9. Performing Organization Name and Address. For in-house reports enter the name and address, including office symbol, of the performing activity. For contractor or grantee reports enter the name and address of the contractor or grantee who prepared the report and identify the appropriate corporate division, school, laboratory, etc., of the author. List city, state, and ZIP Code.

Block 10. Program Element, Project, Task Area, and Work Unit Numbers. Enter here the number code from the applicable Department of Defense form, such as the DD Form 1498, "Research and Technology Work Unit Summary" or the DD Form 1634. "Research and Development Planning Summary," which identifies the program element, project, task area, and work unit or equivalent under which the work was authorized.

Block 11. Controlling Office Name and Address. Enter the full, official name and address, including office symbol, of the controlling office. *(Equates to funding/sponsoring agency. For definition see DoD Directive 5200.20, "Distribution Statements on Technical Documents.")*

Block 12. Report Date. Enter here the day, month, and year or month and year as shown on the cover.

Block 13. Number of Pages. Enter the total number of pages.

Block 14. Monitoring Agency Name and Address *(if different from Controlling Office)*. For use when the controlling or funding office does not directly administer a project, contract, or grant, but delegates the administrative responsibility to another organization.

Blocks 15 & 15a. Security Classification of the Report: Declassification/Downgrading Schedule of the Report. Enter in 15 the highest classification of the report. If appropriate, enter in 15a the declassification/downgrading schedule of the report, using the abbreviations for declassification/downgrading schedules listed in paragraph 4-207 of DoD 5200.1-R.

Block 16. Distribution Statement of the Report. Insert here the applicable distribution statement of the report from DoD Directive 5200.20, "Distribution Statements on Technical Documents."

Block 17. Distribution Statement *(of the abstract entered in Block 20, if different from the distribution statement of the report)*. Insert here the applicable distribution statement of the abstract from DoD Directive 5200.20, "Distribution Statements on Technical Documents."

Block 18. Supplementary Notes. Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of *(or by)* . . . Presented at conference of . . . To be published in . . .

Block 19. Key Words. Select terms or short phrases that identify the principal subjects covered in the report, and are sufficiently specific and precise to be used as index entries for cataloging, conforming to standard terminology. The DoD "Thesaurus of Engineering and Scientific Terms" *(TEST)*, AD-672 000, can be helpful.

Block 20. Abstract. The abstract should be a brief *(not to exceed 200 words)* factual summary of the most significant information contained in the report. If possible, the abstract of a classified report should be unclassified and the abstract to an unclassified report should consist of publicly- releasable information. If the report contains a significant bibliography or literature survey, mention it here. For information on preparing abstracts see "Abstracting Scientific and Technical Reports of Defense-Sponsored RDT&E," AD-667 000.

DOCUMENT 314-77

REAL-TIME METHODS OF INSTRUMENTATION COMBINATION AND DATA SELECTION FOR RANGE SAFETY CALCULATIONS

Range Safety Group
Range Commanders Council

April 1977

Published by

Secretariat
Range Commanders Council
White Sands Missile Range,
New Mexico 88002

TABLE OF CONTENTS

FOREWORD.................................... v

1.0 INTRODUCTION............................ 1
1.1 Background.............................. 1
1.2 Task.................................... 1
  1.2.1 Scope and Objective................. 1
  1.2.2 Justification....................... 2
  1.2.3 Method of Accomplishment............ 3
  1.2.4 Chronology and Significant Events... 3

2.0 DISCUSSION.............................. 4
2.1 Instrumentation Measurements............ 5
2.2 Data Selection Requirements............. 9
2.3 Rationale for Data Combination.......... 12

3.0 TECHNIQUES OF DATA COMBINATION AND SELECTION............................... 14
3.1 Methods of Selection.................... 14
  3.1.1 Preplanned Sequence................. 14
  3.1.2 Dynamic Consideration............... 15
3.2 Methods of Data Combination............. 16
  3.2.1 Multiple Radar Data Combination..... 16
  3.2.2 Determinate Data Combination........ 17

4.0 INDIVIDUAL RANGE DATA COMBINATION AND SELECTION TECHNIQUE..................... 19
4.1 Air Force Eastern Test Range............ 19
4.2 Pacific Missile Test Center............. 23
4.3 Space and Missile Test Center........... 29
4.4 NASA-Wallops Station.................... 33
4.5 White Sands Missile Range............... 41
4.6 Kwajalein Missile Range................. 43
4.7 Armament Development and Test Center.... 53

FOREWORD

The goal of Range Safety is the prevention of injury to personnel or damage to property by taking all reasonable precautions consistent with operational requirements. This is dependent not only on precautions taken in the preparation of a missile or vehicle launch, but in the ability of the Range Safety Officer (RSO) to maintain surveillance during flight to insure compliance with established safety criteria. To maintain this necessary surveillance, the RSO must have at his disposal information depicting performance of the missile and possible impact locations for comparison against predetermined destruct criteria, as well as assurance that his entire safety system is in operational condition at all times. Selection of the best available data and combination of the data from appropriate sources is necessary to insure that the Flight Safety Officer (FSO) has a clear, concise understanding of the vehicle's performance.

A survey of seven of the test ranges represented in the Range Safety Group (RSG) of the Range Commanders Council (RCC) was made to determine the real-time methods of selection and combination currently in use at the various ranges. This information is presented in this document to assist all ranges in determining which systems may have merit for their application and to provide some insight into future applications.

1.0 INTRODUCTION

1.1 Background

The Flight Safety Data Working Group (FSDWG) was established at the 17th meeting of the Inter-Range Missile Flight Safety Group (IRMFSG) for the purpose of assisting the IRMFSG in the preparation of specific tasks of interest to RCC member ranges. At the 30th meeting of the IRMFSG in March 1971, Task 12-30 was assigned to the FSDWG to prepare a report on methods currently being used at the various ranges for combining instrumentation and selecting data for Range Safety calculations. As a result of the reorganization within the RCC, the IRMFSG was renamed the Range Safety Group (RSG), and all responsibilities for tasks relating to Range Safety were placed under its control. At the 31st meeting of this group, September 1971, the FSDWG was disbanded and control of this task was transferred to an ad hoc committee under the RSG.

1.2 Task

1.2.1 Scope and Objective

The scope of this task covers the analytical description of operational methods of real-time data combination and selection presently employed by RCC member ranges. It includes methods of data combination which have been analyzed but not implemented, and a general outline of methods which have been conceived but not studied and evaluated completely.

The objective is to promote the exchange of ideas among member ranges, document methods of data combination and selection of real-time data for flight safety calculations, and to detect future trends which may provide more accurate and reliable data for presentation to the RSO. Through the exchange of ideas and information, member ranges may develop combinations by which they may make better use of existing information. This document may, in some instances, allow a member range to improve flight safety data by adding new instrumentation at a site for use in combination with existing instrumentation. This objective is, of course, secondary to improving the flight safety system performance through appropriate combination of data from existing instrumentation. Through promotion of a general understanding of the potential of data combination, this document may facilitate advancement of the state-of-the-art in data combination and selection at member ranges.

1.2.2 Justification

The identification and documentation of techniques presently employed at the member ranges will prevent redundant analysis in the areas of data combination and selection. One range can certainly benefit from the experience gained by another in areas of common interest. Parallel analysis is almost always required, to a limited extent, for two or more ranges to implement a similar technique. There are enough subtle differences in important areas such as instrumentation capability,

location, geometry, look angles and trajectories flown, which would in most cases prevent one range from blindly implementing another's techniques. The basic work is beneficial; however, it must be tailored for specific use. Other objectives are to facilitate more effective utilization of existing instrumentation, to make available current documentation of the techniques employed in data combination and selection at the member ranges and to provide an avenue of information dissemination among member ranges in this area.

1.2.3 Method of Accomplishment

The Flight Safety Data Working Group, consisting of representatives from Air Force Eastern Test Range (AFETR, SAMTEC-DET-#1), Space and Missile Test Center (SAMTEC), Kwajalein Missile Range (KMR), NASA-Wallops, Pacific Missile Test Center (PMTC), Space and Missile Systems Organization (SAMSO) and White Sands Missile Range (WSMR), prepared the task statement and outline of the document. Each member range then submitted a report of its current practice in the area, a summary of recent range research on the subject, and a list of other methods which may be worthy of detailed study. An ad hoc committee was established to develop the general content of the document and present a draft to members for review. The ad hoc committee was reestablished to revise and add an ADTC section in March 1976.

1.2.4 Chronology of Significant Events

Following are the significant events leading to the completion of Task 12-30:

(1) The task was initiated and plans were developed at the 12th meeting of the FSDWG in June 1970.

(2) An outline and the definition of data systems were presented to the FSDWG at the 13th meeting in October 1970.

(3) The task was officially assigned to the FSDWG by the IRMFSG during the 30th meeting in March 1971.

(4) A description of specific data selection and compilation methods was assembled and presented to the FSDWG at the 14th meeting in June 1971.

(5) The FSDWG was dissolved as a result of reorganizing the RCC, and an *ad hoc* committee was formed in September 1971 to complete the task.

(6) The ad hoc committee met in February 1972 for preparation of the draft document.

(7) A combined meeting of the contributors was held in February 1972 for review of the draft.

(8) The final draft was presented to the RSG for publication in April 1972.

(9) Ad hoc committee revised the original publication in September 1976.

2.0 DISCUSSION

The principal function of a real-time missile flight

safety computer program is to provide the best available information for use in making judgments concerning the safe flight of a vehicle in real time. This information is based upon the best usage and processing of all available sources of real-time measurement data.

2.1 Instrumentation Measurements

2.1.1 A wide variety of measurements of various instrumentation systems is used to provide the FSO with information required for decision making. This section is concerned with those instrumentation systems and the data which are input into the real-time computer. Historically, pulse radars have been the more popular of the real-time Range Safety instrumentation systems. These types of radars measure the position vector only, (i.e., range (R), azimuth (A), and elevation (E)). Recently, doppler rate measurement devices have been added to some of these pulse radars to allow direct measurement of range rate. Most of these devices, with the exception of the FPS-16 rate kits, can operate with or without a coherent beacon; however, more accurate range rate measurement is obtained with the coherent beacon. Coherent beacons have been developed and future usage is expected to increase.

Continuous wave (CW) systems are used where extremely accurate position and velocity measurements are required. These can serve the dual purposes of guidance system evaluation and range safety.

These systems are expensive to purchase and operate, and normally require expensive special-purpose tran-

sponders on board the vehicle. There are other varied types of measurement systems in use at the member ranges. Some of these measure range rate through interferometer techniques; others measure range rate from doppler frequency shifts. Many of these systems are mobile sensors. Several in combination may be required to produce either a position vector for differentiation or a velocity vector for combination with position measured from other sources.

Data available from missile guidance systems, both inertial and radio, have gained in usage in Range Safety computations. Most radio guidance systems are either pulse radars or CW systems, as discussed above. Data from inertial guidance systems have gained usage, primarily due to the lack of sufficient accuracy obtained through either pulse or CW systems. The use of telemetered inertial guidance data for Range Safety purposes is questionable from the standpoint that the system which is guiding a malfunctioning missile is also being used in the computations to determine whether it should be destroyed. However, experience has shown that the earliest indication of a malfunction is often obtained through on-board measurements.

2.1.1.1 Instrumentation systems currently installed and operating at the member ranges are identified in Table 1.

2.1.1.2 Few major additions with the exception of Laser measurements, are planned in the immediate future in the area of instrumentation systems. MPS-36 radars

TABLE 1

Installed Range Instrumentation Systems

DESCRIPTION	DATA OBSERVED	TRACKING** MODE	MANUFACTURER	RANGE*
A. Pulse Radars				
MOD II	R,A,E	T,S	REEVES	1
MOD IV	R,A,E		WECo	1
AN/FPS-16	R,A,E,($\dot{R}$)[2,3]	T,S	RCA	1,2,3,4, 5,7
AN/FPQ-6	R,A,E,$\dot{R}$	T,S	RCA	2,5
AN/TPQ-18	R,A,E,$\dot{R}$	T,S	RCA	2,6
AN/MPS-25	R,A,E	T,S	RCA	1,3,4,7
MPS-19	R,A,E	T,S	REEVES	5
SPANDAR	R,A,E,$\dot{R}$	T,S		5
AN/FPQ-10	R,A,E	T,S	Sperry	4,7
AN/FPS-13	R,A,E***	S	RCA	1
MPS-36	R,A,E,$\dot{R}$	T,S	RCA	2,3,6
AN/FPQ-14	R,A,[illegible]**	T,S	RCA	1
ALCOR	R,A,E****	T,S	RCA	6
B. CW Systems				
GERTS	R,A,E,$\dot{R}$,$\dot{P}$,$\dot{Q}$	T	GE	2
AME	X,Y,Z	T		3
C. Guidance Systems				
Inertial	Position & Velocity	Telemetry		1,2,4
Radio	R,A,E,			1,2,6

*1 = ETR, 2 = SAMTEC, 3 = WSMR, 4 = PMTC, 5 = Wallops, 6 = KMR, 7 = ADTC

$()^X$ Denotes additional capability existing at X range over and above the standard

**T = Transponder or beacon; S = Skin tracking

*** Data observed in R,A,E, but output in geocentric, earth fixed EFGEFG position and velocity.

****ARPA Lincoln C-Band Observables Radar

have been procured by WSMR, KMR and SAMTEC for mobile support; however, these represent only an increase in the number and mobility of sensors without any major technical breakthroughs. Existing instrumentation systems are expected to be, for the most part, representative of future systems. Employing a flight-rated coherent beacon will result in more accurate range rate measurements. Efforts in radar calibration are expected to be rewarding in terms of improved accuracies. Telemetered measurements from airborne sensors, in addition to those obtained from the inertial guidance systems, such as guidance commands, nozzle deflections and pitch, yaw and roll rates, are expected to be used more in real-time Range Safety computations. Combining all of the information now available from radar observations with that obtained through telemetered inertial guidance data and vehicle body sensors can result in much improvement in the information available through use of the real-time computer. With upgraded computers and adequate models much can be accomplished with the information currently available through existing instrumentation and telemetry systems.

2.1.2 Range safety computation and display equipment, both that now in use and that planned for installation in the future, represents a variety of well known companies. Supervisory software techniques employed with computational equipment, while quite varied among member ranges, generally fall within two categories:

(1) Dedication of a computer system to the solution of Range Safety problems, which is noted in the next two subsections as Dedicated (D); (2) Operation within

a multiprogrammed and possibly multiprocessor environment which allows other unrelated data processing to continue concurrently with the real-time Range Safety calculation, and which is noted in the next two subsections as Shared (S). Display equipment in use for presenting Range Safety calculations are Plotters (P), Digital Displays (DD), Cathode Ray Tubes (CRT), Teletype (TTY), and Lighted Matrices (LM). Lighted matrices are generally used to present instrumentation and measurement data status.

2.1.2.1 Presently Installed Systems

RANGE	COMPUTER	COMPUTER USAGE	DISPLAY EQUIP.
SAMTEC	IBM-7044/CDC-3300	D	P,LM
AFETR	CDC-3600	D	P,CRT,LM,DD
NASA-Wallops	HW-625	D,S	DD,P,CRT,TTY,LM
WSMR	Univac 1108	D,S	P,DD,LM,TTY
PMTC	Univac 1230/1212	D	P,LM
KMR	CDC-7600/PDP 11-05	S	CRT,LM
ADTC	CDC-6600/IBM 360-65/ PDP-15/PDP-11	D,S	CRT,P

2.1.2.2 Planned Future Systems

SAMTEC	IBM 360-65 to be replaced by IBM 370-165	D	P,DD,CRT,LM
AFETR	Upgraded System Planned	D,S	P,CRT,LM,DD
NASA-Wallops	None		P,TTY,LM,Expanded Use of CRT
WSMR	Upgraded System Planned	D,S	P,DD,LM,CRT,TTY

2.2 Data Selection Requirements

The objective of a data selection scheme is to examine all incoming data which could be used in computing the primary impact location and other vital displays to be presented to the Missile Flight Safety Officer. Following are three basic types of data selection routines in use at the National Ranges:

(1) Automatic source select

(2) Manual source select

(3) Hybrids of one and two

A discussion of the advantages and disadvantages of the three types of source select schemes will follow. The primary advantage of an automatic or computer processed source select scheme is that it can examine all of the data sources on each computer cycle without the necessary computation required for actual display of the data for human observance. As a consequence, decisions can be made very rapidly. The calculations can be as sophisticated as desired within the capability of the real-time computer to process all required calculations within its basic cycle time.

Major disadvantages of computer source selection are that a program cannot be written which will handle all possible situations it might be called upon to evaluate, and the computer's inability to "learn" from past experience without lengthy reprogramming and checkout effort. Another disadvantage in automatic source selection is that the computer may select a different source with each cycle unless protection logic is programmed. A manual selection with a trained human operator is clearly superior in instances where an unusual event occurs or when deductive reasoning is required. The human operator must have an appropriate interface with the computer in order to allow him to observe the performance of multiple instrumentation systems. This interface may be in the form of status indicators, alphanumeric information, or plots of

various calculations. The human operator cannot comprehend or respond to events with the same speed as the computer.

A hybrid source selection scheme which has most of the advantages of both of the aforementioned schemes can be developed and operationally implemented. All the source select routines in current operation at the surveyed ranges are of the hybrid type. The extent to which the man interacts with the computer to perform the selection operation varies considerably. The objective of a hybrid select scheme is to take advantage of the functions that the computer does best; namely, speed and accuracy of computations and decisions while allowing the man's assistance to diagnose and avoid unusual occurrences and to readily learn from past experience. In general, source selection schemes may consider prior information such as (1) anticipated acquisition time, (2) anticipated loss of track time, (3) anticipated data quality based upon the instrument's basic capability, and (4) its historical performance capability.

In real time, the source selection scheme may consider such parameters as:

(1) Instrument auto track indicator

(2) Parity indicators

(3) Radar automatic gain control circuitry outputs

(4) Side lobe track detection

(5) Agreement tests between various sensors

(6) Comparisons with nominal trajectory

(7) Measurement data variance

2.3 Rationale for Data Combination

Historically, typical source select schemes have chosen the "best' or "best and second best" from among the available data and disregarded all other data as being less important. There has been limited usage of combination of measurements from multiple sources. Of note in this area are ETR's trilateration, PMTC's radar/telemetry composite, and WSMR's combination of radar and range rate data. Recently post operation data reduction techniques have employed best estimate in trajectory determination, which uses all valid data with appropriate weighting to significantly improve the data which could be obtained from a single source. Several passes can, in data processing, be used to try different combinations and to optimize the final result. For real-time applications, only one pass is possible with no valid opportunity for another attempt.

It is extremely important to distinguish between real-time solutions of problems concerning data combination and selection and post-flight data reduction methods. The optimum method for problem solution in a real-time computational environment may differ greatly from what is known to be the "actual" optimum method of solution.

In a real-time computational environment, calculations generally must be made at a fixed cyclic rate. This rate is generally determined by instrumentation measurement/transmission rates and/or desired data output (display) rates. This fixed cyclic rate may also be determined by the amount of calculations required during each program cycle as opposed to the capability of the computer system to be used for implementation. This leads to the fact that methods of data combination and selection to be chosen for solution of problems in a real-time environment are influenced, to a large extent, by the power of the computer system on which the technique will be implemented.

The improvement in data quality by combining information from several radars can be seen by comparing the effects of the error in the total system with that of the individual radars. It can be shown that if σ_{Ri} is the standard deviation in range for a given radar, with appropriate combination of data from n colocated radars the variance in range for the combined system is reduced. That is:

$$\sigma_R^2 = \frac{1}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

To demonstrate this improvement, consider the effect of combining data from three radars with standard deviations in range, as follows:

$\sigma_1 = 5$ ft

$\sigma_2 = 8$ ft

$\sigma_3 = 10$ ft

If the bias is assumed to be zero, the combined error σ_R becomes:

$$\sigma_R^2 = \frac{1}{\frac{1}{5^2} + \frac{1}{8^2} + \frac{1}{10^2}}$$

$$\sigma_R^2 = 15.24$$

$$\sigma_R = 3.9 \text{ feet}$$

The error in the combined system is thereby decreased by 22 percent over that of the best of the individual data sources.

The maximum noise reduction occurs when all σ_i are equal (disregarding the trivial σ=0 case). Then the resulting variance becomes:

$$\sigma_R^2 = \frac{1}{\frac{n}{\sigma^2}} \quad \text{or}$$

$$\sigma_R = \frac{\sigma}{\sqrt{n}}$$

3.0 TECHNIQUES OF DATA COMBINATION AND SELECTION

3.1 Methods of Selection

This subparagraph discusses the selection procedures used when a single "best" source is input to the Impact Predictor (IP) computations.

3.1.1 Preplanned Sequence

The preplanned sequence techniques use priority tables where there is a priority order of sources for various time periods after liftoff. In these systems the highest priority source is selected if it meets other criteria such as an on-track indication, data parity

checks, and editing limits. If the highest priority source does not meet these criteria, then the second highest source is examined. The priority order changes normally as a function of time after liftoff. Sensor priorities change as their tracking geometries change with new downrange sensors being used later in flight.

3.1.2 Dynamic Considerations

The various methods of selecting data sources based on real-time dynamic considerations depend on some estimate of data quality or accuracy. Most of these selections are based on real-time estimates of data noise which are obtained by comparing actual measurements to predicted values of the measurements developed from numerical filters. In most cases these noise estimates are made in the measurement system (i.e., RAE), but in some cases the estimates are made in the Cartesian coordinate system in which the data is filtered. The noise estimates often are then transformed into another coordinate system for source selection. In addition to noise, various other factors can be used to determine which data source to select. Selection can be based on a total position error from the three components of the data or on the off-range or cross-range component of the position data. Also, selection may be made on the area of the 95 percent probability-impact ellipse. The selection is then made on the basis of minimal error.

Other checks such as on-track, parity and editing are also made. In cases where there are three or more sources it is often necessary to check to determine if all sources are tracking the same object, and if one is not it is considered an invalid source for combining with other radars.

3.2 Methods of Data Combination

3.2.1 Multiple Radar Data Combination

It has been shown in subparagraph 2.3 that it is possible, by means of weighted averaging, to combine two or more noisy measurements and obtain an average which is less noisy than the best of the single measurements. One of the simplest methods involves two systems located at the same site. In this case the data can be combined in the radar, range, azimuth and elevation coordinate system. The range data from the two radars is weighted in inverse proportion to the variance.

$$R_c = \frac{\sigma_2^2 R_1 + \sigma_1^2 R_2}{\sigma_2^2 + \sigma_1^2}$$

The azimuth and elevation data are combined in the same way. The advantage in this method is that if, for example, radar one is noisy in azimuth and smooth in elevation when radar two is noisy in elevation and smooth in azimuth, data is obtained which is smooth in both axes. Also if both radars have equal noise in one axis then the noise in the combined measurements is reduced by approximately 30 percent. Unless the radars are very close, relative to the tracking range, some parallax correction must be made in order to use this method. More commonly, there are several radars spread out relative to the missile trajectory. In these cases the combination must be made in one common coordinate system and a limited number of the sources are input to the combinations during one time period. The selection of the set of sources to be input to the combination is made in a similar manner to the selection of single

sources discussed in subparagraph 3.1.1. One set of sources is used in the launch area and, as the missile flies, downrange radars are added to the set and launch area radars are deleted. The tracking data from the various sources and their associated variances are transformed into a Cartesian coordinate system and the data are combined in inverse proportion to their variances. This technique is not optimum, since in transforming into the Cartesian system the accuracy of precise range data from a radar will usually be diluted by noisy angle data. However, this system is a good reliable compromise between a single source selection and more complex optimal combination schemes. The more complicated optimal combination schemes require transforming the estimated variances of all sources from the radar polar coordinates into variance-covariance matrices in the common Cartesian system. Two vectors may be combined in an optimum (maximum variance) sense similar to the combination of scalars described above.

$$X_c = [C_2 x_1 + C_1 x_2] \quad [C_1 + C_2]^{-1}$$

This solution can be expanded for more than two sources in the following manner:

$$X_c = \left[\sum_{i=1}^{M} C_i^{-1} \, xi \right] \left[\sum_{i=1}^{M} C_i^{-1} \right]^{-1}$$

Further extension of these techniques leads to the more complex case of inputting all data sources into a Kalman filter and doing the data combination along with the filtering.

3.2.2 Determinate Data Combination

3.2.2.1 Determinate data combination is defined as combining measurements (usually all angles or all

ranges) from two or more instruments to form a solution of space position. A minimum of three measurements in any combination of range and/or angles from at least two suitably located instrumentation sites are required to form a two station space position solution. Computational time requirements increase with the addition of more measurement data from additional instrumentation, but precision and accuracy may also be enhanced depending on the geometry of instrumentation placement.

The most simple case is the two station solution which makes it a good example for further discussion. Many methods of combining the measurements exist but basically they all begin in essentially the same way. Consider the case of two instruments, each measuring two angles: azimuth and elevation. Knowing the distance between the sites (the baseline), one can take two angles from one site and one angle from the other and derive space position. Similarly, one can use a different combination of angles to form a second space position. Adding more stations and more measurements yields more solutions of space positions. The methods by which these multiple solutions of space position are combined to yield an optimal estimate of space position are generally how the different techniques of determinate data combination differ.

3.2.2.2 Selection of the Best Determinate Data Combination

Because of computational time constraints, it is usually not feasible to consider all possible combinations of instruments for a multiple station space position

solution in a real-time environment, though this would probably be done in a post-flight data reduction situation. An example of an effective scheme for choosing the best approximation of space position from several two station determinate data combinations is as follows:

(1) Eliminate those stations not indicating track.

(2) Compute two station solutions of space position according to geometrical considerations.

(3) Save the difference between the two solutions of space position computed during each two station solution.

(4) Compute a variance on the difference from each two station solution.

(5) Assuming the difference is small enough to indicate unbiased track, choose the two station solution with the minimum difference variance.

4.0 INDIVIDUAL RANGE DATA COMBINATION AND SELECTION TECHNIQUE

4.1 Eastern Test Range (ETR)

4.1.1 Existing Techniques

There are, at present, two methods for providing position to the IP. One method is the position of the best radar of the set being input to the computer. The other method is the position from a trilateration solution.

4.1.1.1 Method

All data from those radars supporting the test are input to the real-time program. The data from each radar are edited by use of a second order exponential filter and the content of the random noise present in the data is estimated by a third order exponential filter. Errors in azimuth, elevation and range are transformed to an earth centered coordinate system and propagated from this point in space to the instantaneous impact point. At the impact point, the errors are expressed as covariances in latitude and longitude and then as a 95 percent confidence ellipse. Therefore, there is an error ellipse associated with each radar from which the radars can be ordered according to quality. Additionally, other factors are accounted for such as (1) track status, (2) validity, (3) manual intervention, and (4) off-range error. If any radar is not on track or its position data is invalid, its error ellipse is magnified by some large factor to prevent selection.

To establish data validity, position data from two or more radars are compared and must agree within predetermined limits. A radar is disqualified if its data disagrees with data from two or more other radars which are in agreement. The limit of agreement increases as the distance from the launch site increases. Expansion of the agreement limit is determined by a time table which is correlated to vehicle velocity.

Selection is determined by the area of the 95 percent confidence ellipse and off-range error. Once the selection has been made it remains fixed until such

time as the area of the ellipse computed from the selected radar decreases by 12.5 percent, an empirically determined factor to prevent unnecessary switching between radars.

In the second method of computing position by trilateration, ranges from three radars are used to compute the earth centered coordinates at each time. The solution is unique since it is assumed that the three vectors intersect. From this assumption, it is necessary that the data be time-correlated, otherwise the wrong position will result. If all radars tracked the same object many combinations of three radars are possible, some of which are not valuable due to poor geometry. For example, they may lie in a straight line. Consequently, certain combinations of radars are treated as single sites in order to get the best representation. There are three groups of sites:

(1) BDA-16 BDA-18

(2) 0.18, 19.18, 3.13

(3) 91.18, 7.18

Radar 1.16 is not included in these groups because its data is difficult to correlate in time with the other radars.

Only one radar from each of the three groups is used in the trilateration solution. Each of the radars are checked for the following:

(1) Scheduled for test and object

(2) Sigma range

(3) Manual rejection

(4) Track status

(5) Time correlation

If the status of the radar is favorable in all of these conditions then it is accepted as a possible source for the trilateration solution. If not, its sigma range value is raised to bias against accepting the radar.

As in the single station solution, once a combination of radars has been chosen the sigma range for each is reduced by 12.5 percent to prevent excessive changes in the radars being combined for the solution.

The choice of radars for the trilateration solution is made as follows:

(1) Choose the Bermuda radar with the lowest sigma range and less than 28 feet. If neither radar passes the test, choose automatically among all radars that which has the lowest sigma range.

(2) For the second choice, bias against the first radar. If 7.18 or 91.18 has not been selected in step (1), choose that with the lowest sigma range and less than 28 feet. If neither radar meets this limit, automatically select among the radars, outside of that selected in step (1), the radar with the lowest sigma range.

(3) Excluding the two radars selected in steps (1) and (2) and the groups in which they are placed, choose as the third radar that which has the lowest sigma range.

4.1.2 Planned Future Techniques

Future techniques planned at the ETR include expansion of guidance telemetry data usage to include all missile types launched from the ETR having an inertial guidance system.

Additionally, the trilateration solution can be expanded to accept range-rate data if radars are modified for the rate measurements. This will permit determination of a unique position and velocity vector at each time point.

4.2 Pacific Missile Test Center (PMTC)

4.2.1 Translating Data Technique

4.2.1.1 Method

There are two distinct methods used at Pacific Missile Test Center (PMTC) in the data combination and selection scheme. The first system that will be discussed is now used on the USNS WHEELING. In this case the technique that is used is to combine radar data from the two radars in range, azimuth, and elevation on the basis of minimum variance. Since the radars are aboard ship, and located very close together, a simple technique is used to parallax one radar to the site of the other.

This is done before combination. The combination is made in the deck coordinate system so that it is the measured range, azimuth and elevation at the radars. Once this combination is made, the data from two radars individually, and also from the combination, are transformed into a local tangent plan system. In this case they are handled as three separate sources. This data is then analyzed to determine the minimum cross-range variance. The selection of the data source to be used in the radar Instantaneous Impact Prediction (IIP) source is made on the basis of this variance. Normally, the combined source is expected to be least noisy and therefore, is selected. There were some problems in setting up the original combination scheme; therefore, the selection was put in as a safeguard against errors in combination. Further data combination is made to produce the composite radar/telemetry IIP. This composite IIP is a weighted combination of data based on guidance, telemetry information, and data from radar. This scheme is used in the composite IIP to determine biases in the initial conditions by comparing the existing composite solution to that solution from radar. The biases are then recursively corrected to make the composite solution tend to agree with the radar solution. The weighting chosen on this recursive update of the biases has been 1/100. In other words, on every iteration the biases are corrected to move the composite solution 1/100 of the way to the radar solution. This is done independently in the X, Y, Z, and $\dot{X}$, $\dot{Y}$, $\dot{Z}$ components.

4.2.1.2 Accuracy Considerations

The improvements in accuracy which have been achieved

by data combinations have varied from a small improvement over a selecton scheme in cases where one radar has had a definite accuracy advantage, to other cases where something approaching the theoretical limit was achieved, improving accuracy by approximately 30 percent over the single source solution. The source selection between the composite and the individual solution has provided an effective safeguard against erroneous tracking data.

4.2.1.3 Timing

In all of PMTC's systems the sources are in proximity (this is particularly true on the WHEELING, and also on the system used in the Point Mugu/San Nicolas Island area). There are no problems due to asynchronous data, since a complete solution from each source is used. By adding these complete solutions, none of the time lag problems associated with multilateration systems from remote stations have been experienced.

4.2.2 N-Station Solution Technique

The second type of system is that used with multiple radar data in the Point Mugu/San Nicolas Island complex and the Pacific Missile Range Facility, Barking Sands, Kauai, Hawaii.

4.2.2.1 Method

The method involves using the spherical radar data and converting this data to Cartesian coordinates. The Cartesian data are referenced to a common point. Assuming there is more than one set of radar data (one

set is trivial) the cross coordinate deviations are found for each radar by the formulae

$$\sigma_x = \{[\sigma_R \cos E \sin(A-\varphi)]^2 + [\sigma_A R \cos E \cos(A-\varphi)]^2 + [\sigma_E R \sin E \sin(A-\varphi)]^2\}^{1/2}$$

$$\sigma_y = \{[\sigma_R \cos E \cos(A-\varphi)]^2 + [\sigma_A R \cos E \sin(A-\varphi)]^2 + [\sigma_E R \sin E \cos(A-\varphi)]^2\}^{1/2}$$

$$\sigma_z = \{[\sigma_E R \sin E]^2 + [\sigma_R \sin E]^2\}^{1/2}$$

where

σ_R, σ_R, and σ_E are the standard deviation of range (in feet), azimuth and elevation (in radians) and σ_x, σ_y, and σ_z are in feet.

R, A, and E are the edited range, azimuth, and elevation (the editing consists of testing for bit dropouts and spurious points).

φ is the orientation of the positive x axis so that effectively 0° azimuth is coincident with the x axis.

Weights are computed as

$$W_{P_i} = 1 - \frac{\sigma_{P_i} \; |P-P_{o_i}|_i}{\sum_{j=1}^{N} \sigma_{P_j} \; |P-P_{o_i}|_j}$$

for the contribution of each component of each radar; the weights of the different components of the same radar may be different where

P = the N-station solution, X, Y, or Z from the previous sample

P_{oi} = the smoothed X, Y, or Z of this sample of the i^{th} radar

$i = i^{th}$ radar

N = total number of radars that are tracking the vehicle

From the weights and the smoothed positions and computed velocities and accelerations a best estimate of the vehicle behavior may be obtained by

$$P_o = \sum_{i=1}^{N} W_{P_i} P_{o_i}$$

$$V_o = \sum_{i=1}^{N} W_{P_i} V_{o_i}$$

$$A_o = \sum_{i=1}^{N} W_{P_i} A_{o_i}$$

where the weight for the X component for the i^{th} radar is used for the X component of the velocity and acceleration; Y and Z are processed using the respective weights. The symbols V_o and A_o are for the velocity and acceleration components.

The final computations are the prediction of the N-station solution for the next sample

$$P = P_o + V_o \Delta t + (A_o \Delta t^2)/2$$

where

Δt = the time difference between samples of data

4.2.2.2 Initial Conditions

To start the N-station solution process, at least one radar must be on track, presumably on the object of

interest. With one radar, the solution is trivial using the data of that radar.

When a second radar comes on track, the weight for each component is set to one-half.

When additional radars come on track, their data are included as if they had been on track before, with no consideration to resetting the weights so each radar contributes equally to the solution.

4.2.2.3 Restrictions

If the difference between a smoothed component and the N-station solution is greater than some value (usually 500 feet) all of the data for that radar are rejected for that sample. If the data from all the radars are rejected because the values are beyond acceptable limits, the means are used as outlined in the initial conditions.

4.2.2.4 Accuracy

The only reliable measurement of accuracy is based on the use of the combined data from this algorithm as inputs to a set of routines to predict the location of a vehicle in flight some 150 seconds hence. The purpose was to photograph the vehicle at a given time and, by using the combined data, the trajectory was extrapolated and angles from a camera to the predicted location were generated. The camera had a field of view tolerance of 1/4 degree in azimuth or 1/4 degree in elevation, and the predictions generated data so that the vehicle was within this field of view. One time the photographed vehicle was on the cross hairs of the camera lens.

4.3 Space and Missile Test Center (SAMTEC)

4.3.1 Existing Techniques

The primary real-time flight safety program operation on the IBM 7044 computer automatically selects the "best" source based upon comparison of the cross-range variance in the missile position measurement. The source-select routine does not use velocity parameters for this function. No attempt is made to combine the data from multiple sources in the real-time program. The backup flight safety program operating on the CDC 3300 computer has a manual source select only, with no data combination.

4.3.1.1 The current method of automatic source selection in the Vandenberg Impact Prediction System (VIPS) establishes a priority order dependent on the hardware available for trajectory position and velocity recovery. Data sources with good track and transmission (parity) are considered. The order of selection is the General Electric Range Tracking System (GERTS), Inertial Guidance (IG) via telemetry (one or more receiving stations) and the C-Band Radars. The primary selection of C-band radars is made by the Real-Time Data Controller (RTDC) based on hardware availability and possibility of acquisition during the various phases of the launch operation. Provided the automatic source selection mode has been selected by engaging this switch on the RTDC console, and GERTS and IG data are not selected, the VIPS program will automatically select a C-band radar for plotting. The current criteria for the GERTS

and IG is a priority weight based on an *a priori* determination. If neither of these sources is available or not supplying valid data, then C-band radar selection is made on a minimum cross-range error (CRE) criterion. The radar with the minimum CRE is initially selected from among the valid C-band radars. A change is made only if another C-band sensor has a CRE which is 90 percent or less of the radar which was selected during the past cycle.

4.3.1.2 Accuracy Considerations

Since no combinations of data are performed, the accuracy of the individual single station is prevalent. Typical IIP 3-sigma uncertainty ellipses with beacon track are:

Range	TPQ-18	22.2X22.2Km	(12 X 12 nm)
556 Km			
(300 nm)	TMIG	3.7X3.7Km	(2 X 2 nm)
	FPS-16	37X55.6Km	(20 X 30 nm)
	GERTS	3.7X3.7Km	(2 X 2 nm)
2780 Km	TPQ-18	111.2X55.6	(60 X 30 nm)
(1500 nm)	TMIG	3.7X3.7Km	(2 X 2 nm)
	FPS-16	222.4X111.2Km	(120 X 60 nm)

Studies indicate that an order of magnitude improvement prediction accuracy would result from combining the data from three or more C-band radars with the use of Coherent Signal Processing (CSP) range rate ($\dot{R}$).

4.3.1.3 Timing

The real-time processing of six data sources uses up to 95 percent of the IBM 7044 computer capability, thereby

saturating it. With the transfer of the real-time function to the IBM 360-65 computer, improvement in execution time should result and data combination becomes much more attractive.

4.3.2 Planned Future Techniques

4.3.2.1 Short Term

SAMTEC is currently developing a real-time system on the IBM 360-65. This system is planned to be operational by January 1978. No significant improvements in the area of filtering, editing and source selection are planned. The Initial Operational Capability (Phase I) will include the current VIPS capabilities with specific improvements such as:

a. Capability to Process Input Data from 12 Sensors

The system will have the capability to process up to 12 input data sources such as GERTS, C-band radars, telemetry IG data, etc., during a given mission. At least six of these shall be processed through the data filtering and source selection routines during any given computer cycle. The selection of which six sources to process will be a function of (1) priority tables which identify phases when each source can be expected to have a potential for valid track, (2) a valid on-track indicator, or (3) manual selection. If a sensor that is being processed loses track, it may be replaced with one in reserve with a high priority.

Care must be taken with this concept to avoid excess reinitialization in the filter systems.

b. Automatic Source Selection

An improved data source selection technique will be implemented. The source selection technique will choose the two sensors that have the greatest probability of providing realistic and accurate data for flight safety calculations and displays. This selection technique will include GERTS, radar and telemetry IG data sources as candidate sensors. The following criteria will be included in the source selection technique:

(1) Determination of eligibility including, valid source identification, selected for filtering, on-target indicator and valid data transmission.

(2) Selection of best source is then based upon:

(a) Quality measure including sensor priority, skin or beacon tracking, capability for automatic abort (if required), and previous selection.

(b) Velocity voting, including screening out sensors whose velocity vector deviates from the mean velocity vector more than a preestablished limit.

(c) Weighted CRE

(3) Manual selection through console switches will have override capability over the automatic source selection technique.

4.3.2.2 Long Term

Improved capability is planned to include three significant real-time improvements. These are real-time dynamic debris patterns, a CRT display system and a multistation solution capability. A feasibility study has been conducted to determine the improvement that would result from the implementation of a multistation solution.

4.4 NASA-Wallops Station

4.4.1 Existing Techniques

4.4.1.1 Method of Best Radar Selection

Before automatic selection is accomplished, the following tests must be passed:

(1) Data must be available and the system in autotrack.

(2) Manual override cannot be in control of the selection.

(3) Radar qualifier has been exercised to establish validity of tracking data.

(4) Best radar selector or weighted combination is manually controlled.

Explanations:

(1) Data is available or is not available from the specific radar system.

(2) Personnel at the Real-Time Console (RTC) are assisted by quality status light communications to the radar sites and *a priori* knowledge which cannot be handled as easily by the real-time program. Such information allows the manual override of the automatic selection process.

(3) The most likely time for radar to lose lock on the payload carrier is at stage separation. Thus the qualifier determines during powered stage whether radars are tracking spent or thrusting stages.

(4) Given that data is available, is not manually rejected and is tracking the desired (powered) stage, it is than a candidate to be selected the best or to be combined by statistical weights.

There are two types of manual overriding of data: selection and rejection. In the case of selection, only one radar may be chosen. In this case, it is not necessary to cycle through the best radar selector routine or the weighted combination routine. In the case of rejection there may be two or three radars eligible for selection or combination.

4.4.1.1.1 Radar Qualifier Routine

The radar qualifier is cycled through only during powered flight. It is used to determine if the radars are tracking a thrusting stage. For qualified radars $\lambda_2^i = 1$, unqualified $\lambda_2^i = 0$.

There are two primary paths in this routine. The path of execution is determined by the mode of selection; that is, either best radar selector or weighted combination. The difference between the two paths is that if no radar has been qualified, $\lambda_2^i = 1$ for the best radar last cycle and $\lambda_2^i = 0$ for all others in the best radar selector mode, and λ_2^i is set to either 1 or 0 to indicate radar availability in the weighted combination mode.

There is a built-in ten-cycle delay to give the thrust acceleration filter time to smooth. After this delay the thrust acceleration is tested against an input number. If it is greater for ten consecutive cycles, then the radar is qualified to be selected the best or used for a weighted combination. If a qualified radar becomes unqualified, it must then pass the above test ten consecutive times before it becomes qualified again. If all radars are disqualified after one or more has been qualified, then both ten-cycle delays will be induced on subsequent calls.

4.4.1.1.2 Reject and Select Switching Logic

In terms of hardware, each of the Reject and each of the Select switches are independent of each other. Furthermore, there is no definition in terms of hardware, or of "on" and "off"; that is, they are change-of-state switches.

From the standpoint of software, on the first cycle of execution of the real-time program all of the switches are defined to be "off" (all radars are unselected and

unrejected). Two sets of information are buffered: the bit settings defining "off" and bit settings of last cycles.

The bit settings of the present cycle are compared with those of the last cycle. The ones that differ indicate which switches have been pressed and "off" is redefined to be the bit pattern of the last cycle. If all bits between last and present cycle compare, a comparison is made between the "off" and present pattern of bits to determine which switches are already on.

4.4.1.1.3 Use of Reject/Select Switches

Rules:

(1) The RSO console is not wired for Reject switches.

(2) The RSO Select switches override the switches of the RTC.

(3) The RTC Select switches override the RTC Reject switches.

(4) One, and only one, radar can be selected.

(5) A radar cannot be selected if data from the radar has not been received.

(6) All but one of the radars transmitting data can be rejected.

(7) On the first cycle all the radars are forced to be unselected and unrejected.

In review, the three ways in which radar data can be used are:

(1) Manual Selection

(2) Automatic Best Radar Selection

(3) Updated Statistically Weighted Combination

The second and third modes can be modified by manually rejecting certain radar inputs. That is, if the program is in either one of these modes only unrejected radar data will be considered for automatic selection or a weighted combination.

The first mode is entered when one of the Select switches has been pressed, and can be released from the Manual selection mode only by again pressing the switch corresponding to the radar data selected.

The second and third modes can be entered by pressing one of the spare switches labeled as such on the RTC.

The program also lights the IP radar lights located on both the RTC and the RSO console, indicating which radar data is being used for input/output purposes.

4.4.1.1.4 Updating and Weighted Combination Routine

Updating:

Prior to combining radar data, it must be updated to a

common time, namely TRSO. This is accomplished by the equations:

$$\Delta t_i = TRSO - TPN_i$$

where

TPN_i is the program time that the i^{th} radar interrupted the real-time program.

$$X_{u_i} = X_{I_i} + \dot{X}_{I_i} \Delta t_i + \ddot{X}_{I_i} \Delta t_i^2$$

$$\dot{X}_{u_i} = \dot{X}_{I_i} + \ddot{X}_{I_i} \Delta t_i$$

And similarly for the Y_{u_i} and Z_{u_i} coordinates.

Weighted Combinations:

In position and velocity the data is combined by the equations:

$$X_B = \frac{\sum_{i=1}^{4} \frac{X_{u_i}}{S_{x_i}}}{\sum_{i=1}^{4} \frac{1}{S_{x_i}}} ; \qquad \dot{X}_B = \frac{\sum_{i=1}^{4} \frac{\dot{X}_{u_i}}{S_{\dot{x}_i}}}{\sum_{i=1}^{4} \frac{1}{S_{\dot{x}_i}}}$$

And likewise for

$\dot{Y}_B$, Y_B, Z_B and $\dot{Z}_B$

where

$S_{\dot{x}_i}$, $S_{\dot{y}_i}$, $S_{\dot{z}_i}$

are the covariances of velocity in the earth centered inertial system.

4.4.1.2 Accuracy Considerations

4.4.1.2.1 Best Radar Selection

This routine chooses the best radar data, based on either the area of the impact error ellipse ($\lambda_{16} = 1$) or the covariances of velocity in the earth centered inertial system ($\lambda_{16} = 0$). LOCK 16, (the program name for the flow chart symbol λ_{16}) is input on the permission-generated parameter tape. The covariances and error ellipses are computed in the radar data handling module. In either case, the routine chooses as the best radar the one associated with the smallest numerical value. However, when one radar becomes, so to speak, better than that which is currently best, it will not be chosen to replace the latter until it has been "better" for ten consecutive cycles. On the first cycle through the real-time program, or at any time when the program is switching from another to this mode of picking the best data, passage is made through an initialization path which picks the best radar from scratch.

In using the weighted combination mode the radar qualifier routine becomes all important to prohibit erroneous tracking data from influencing the statistical combination of sources. Of noteworthy importance is the ability to detect thrusting stages at the outset of performance periods. Use of telemetry data will greatly improve the ability to detect these events, and hence, qualify the radar sources. Limited success in weighted combination at Wallops Station has been achieved to date, but,

with future incorporation of telemetry data, refinements are expected.

4.4.1.2.2 Timing Synchronization

Timing synchronization must be accomplished prior to the solution of weighted combination. This is accomplished as presented in subparagraph 4.4.1.1.4.

Timing synchronization is of little importance in the best radar selection determination, but the rate for each source must be constant enough to permit valid data filtering and editing. Computation time is highly dependent upon sample rates and computer memory access time. At present, Wallops Station uses an HW625 computer to perform the calculations for the Range Safety program. Data is entered at 10 pps from four sources. The total cycle time, including filtering, selection, weighted combination, editing, impact calculations and input/output requires approximately 90-94 milliseconds out of an available 100 milliseconds.

4.4.2 Planned Future Techniques

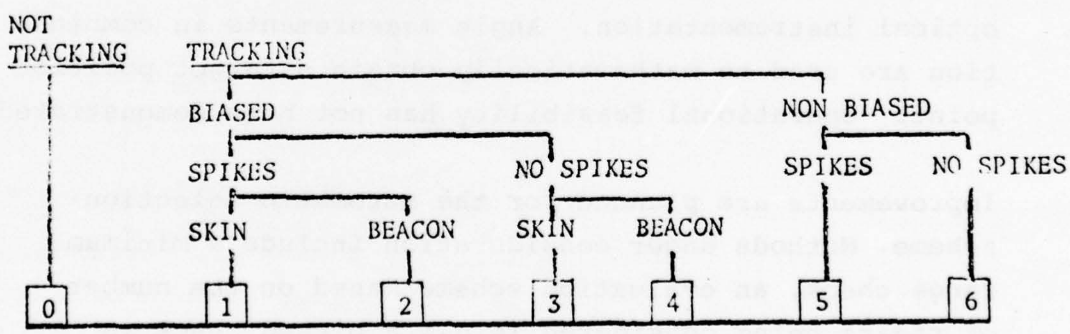
Future refinements to the selection/weighted combination techniques will mainly be incorporated into the radar qualifier routine. Short range refinements will include the incorporation of telemetry data to better detect performance periods in the trajectory. Future range refinements may include modifications to the statistical weighted combination and improvements to the basic radar measurements by incorporation of the pulse doppler (R) measurements available from the FPQ-6 radar system. Additionally, the FPQ-6 radar system will be augmented

by a Laser range measurement system. Both the R and the Laser measurements will greatly improve the weighted combination technique used in Range Safety support.

4.5 White Sands Missile Range (WSMR)

4.5.1 Existing Techniques

WSMR presently uses FPS-16 and MPS-36 radars to meet the bulk of Flight Safety requirements. All participating radar data are transformed to a common earth-centered referenced frame and smoothed by the QD filter. Real-time computations used for all digital, plotter or video displays are made from either a primary or secondary selected source. The primary or secondary source is selected automatically or manually via operator control. The automatic selection scheme is based on a data quality rating system. The following diagram shows the seven categories of data quality.



A radar with a tracking mode other than skin or beacon is considered non-tracking. A radar is also considered non-tracking if any of the following conditions are true:

(1) Filter is not initialized.

(2) Range is less than 1200 feet.

(3) Data link problem is evident.

A radar is considered biased if the total distance from the median radar is greater than 500 feet. A radar data spike is a jump in the actual data when compared to the filter predicted point. Each earth centered component is despiked (component replaced with predicted) if the data jump is greater than 450 feet (program variable nominal value). The final selection is made from instruments in the highest data quality group. The instrument with the lowest "noise" (standard deviation) value within the group is picked. The "noise" value of the previously selected instrument is reduced 20 percent to prevent excessive switching.

4.5.2 Planned Future Techniques

Multiple station solutions have been developed from optical instrumentation. Angle measurements in combination are used to mathematically obtain a target position point. Operational feasibility has not been demonstrated.

Improvements are planned for the automatic selection scheme. Methods under consideration include a minimum range check, an evaluation scheme based on the number of radars being considered (e.g., a biased check is meaningless when only two radars are considered), and long period tracking accuracy determinations.

Future tracking systems other than radar could be greatly beneficial in the assurance tracking data for Flight Safety. A Drone Formation Control System (DFCS)

is slated for installation starting in July 1976. An IBM 360 computer will receive precise range measurements and apply a trilateration solution to obtain drone position data. The DFCS will output position data for reception and use on the UNIVAC 1108 computer. A Three-Object Angle Measuring Equipment (TOAME) contract was awarded to Cubic Corporation in early 1976. The system has many applications when radar coverage is questionable. The system will output three lines of data to the UNIVAC 1108 computer for Flight Safety presentations.

4.6 Kwajalein Missile Range (KMR)

4.6.1 The Kwajalein Range Safety System (KRSS)

KRSS is configured to accept radar tracking data from any of the sensors at the Kwajalein Missile Range. Among these are the ALCOR, ALTAIR, TRADEX, TPQ-18 and two MPS-36 radars. At the present time only the ALCOR, TPQ-18 and the MPS36's are being used in the safety solution since these sensors have a beacon track capability. Of the four, only the MPS-36 data are combined due to their location and the common method of correction of systematic and bias errors. Therefore, the KRSS software is provided with five independent sources from which to choose data for flight safety processing. The following discussion addresses the method used for MPS-36 data combination and radar source selection.

4.6.2 Radar Data Combination Methodology

The improvement in data quality by combining information from several radars was discussed in paragraph 2.3. It is possible by means of weighted averaging to combine

two or more noisy measurements to obtain an average which is less noisy than the best of the single measurements. For two systems located at the same site (the MPS-36A and MPS-36B radars are approximately 50 feet apart), the data can be combined in the radar range, azimuth, and elevation coordinate system. The measurement data from the two radars are weighted in inverse proportion to the variances as discussed in subparagraph 3.2.1 yielding

$$M_c = \frac{\dfrac{M_1}{\sigma^2 M_1} + \dfrac{M_2}{\sigma^2 M_2}}{\dfrac{1}{\sigma^2 M_1} + \dfrac{1}{\sigma^2 M_2}} = \frac{\sigma^2 M_2 * M_1 + \sigma^2 M_1 * M_2}{\sigma^2 M_1 + \sigma^2 M_2} \tag{1}$$

where:

M_c is the combined measurement value; i.e., range, azimuth, or elevation.

$\sigma^2 M_1$, $\sigma^2 M_2$ are the variances of each source measurement; i.e., $\sigma^2 M_1$ is for MPS-36A, $\sigma^2 M_2$ is for MPS-36B.

M_1, M_2 are the measurement values; i.e., range, azimuth, or elevation for each source.

The advantage in this system is that if, for example, one radar is noisy in azimuth and smooth in elevation when the other radar is noisy in elevation and smooth

in azimuth, data are obtained which are smooth in both axes. Also, as previously noted if both radars have equal noise in one axis then the noise in the combined measurements is reduced by approximately 30 percent.

The above method is used when combining the MPS-36A and MPS-36B radar azimuth and elevation data only. The straight arithmetic average of the two radar range measurements is used to obtain the slant range measurement for the combined source since the difference in the radar range variances is very small compared to the total ranges being measured.

To ensure that both radars are tracking the same object, an error tolerance is placed on the differences in each component measurement. This error tolerance is based on past performance of each of the individual radars and is input to the KRSS software as a pre-mission constant. If the difference between radar component measurements (i.e., range, azimuth, and elevation), is within the preselected error tolerance, the data are considered valid for the combination process. The steps in the process for combining the data from the two radars are as follows:

4.6.2.1 The data validity time for the combined MPS-36 data is computed as the arithmetic average of the validity time associated with each of the individual radars.

4.6.2.2 The combined azimuth and elevation data are computed using equation (1) in subparagraph 4.6.2 while the combined range is obtained from the arithmetic average of the range data from each MPS-36.

4.6.2.3 Following the data combination, the combined range, azimuth and elevation are converted to Cartesian coordinates using the following relationships:

$$X_C = R_C \cos (EL_C) \sin (Az_C)$$

$$Y_C = R_C \cos (EL_C) \cos (Az_C)$$

$$Z_C = R_C \sin (EL_C)$$

where:

$\left.\begin{array}{l} X_C \\ Y_C \\ Z_C \end{array}\right\}$ represent the flight safety object position vector components referenced to the radar Cartesian coordinate system.

R_C is the slant range of the flight safety object for the combined source.

EL_C is the elevation angle to the flight safety object for the combined source.

Az_C is the azimuth angle to the flight safety object for the combined source.

4.6.2.4 Prior to transforming the combined source data to the KRSS reference frame, the parameters defining its location must be computed. The origin of the combined source is located midway between the two MPS-36 radars. The combined source location is obtained in the following manner:

$$LAT_c = \frac{LAT_1 + LAT_2}{2}$$

$$LONG_c = \frac{LONG_1 + LONG_2}{2}$$

$$HT_c = \frac{HT_1 + HT_2}{2}$$

where:

LAT_C is the geodetic latitude of the combined source.

$LONG_C$ is the longitude of the combined source.

HT_C is the height above sea level of the combined source.

LAT_1, LAT_2 are the geodetic latitudes of the MPS-36A and B radars.

$LONG_1$, $LONG_2$ are the longitudes of the MPS-36A and B radars.

HT_1, HT_2 are the heights above sea level of the MPS-36A and B radars.

The azimuth of the X-axis for the combined source is set equal to the MPS-36A radar azimuth at this point.

4.6.2.5 The combined source position data is now transformed to the KRSS reference system. This is accomplished in two steps. First, the Cartesian coordinate data is transformed to an Earth Centered Inertial (ECI) reference frame. Second, the combined ECI data is transformed to Cartesian components in the KRSS reference frame. The combined data is then made available to the radar source select scheme discussed in the following paragraphs.

4.6.3 Radar Source Select Methodology

The following discussion presents the methodology and rationale used for selecting the "best" radar input source for use in IIP calculations for each cycle of Flight Safety Routine operation. A measure of radar performance can be made by evaluating the difference between the raw input radar position measurements and the current position estimate. This difference is defined as the residual. It should be noted that the residual measure is also used in obtaining the smoothed estimate of position associated with each radar source. Accuracy of the radar position measurement is influenced by (1) the systematic and (2) the random error of each measurement system. If systematic error corrections are made to the data at the radar site, and if no significant bias errors are introduced in filtering, then the random error has the primary affect on measurement accuracy. The sample variance can be estimated from the measurement data using the following equation:

$$S^2 = \frac{1}{n} \sum_{i=1}^{n} (X_i - \mu)^2 \tag{1}$$

where:

S^2 equals the sample variance

n equals the number of samples considered in the data base

X_i equals raw measurement value

μ equals expected measurement value

The first step in the source selection process is to compute a variable called "intermediate sum," defined by the following recursion relationship:

$$IS_n = C1 * IS_{(n-1)} + C2 * RES_n * RES_n \qquad (2)$$

where:

IS_n equals the intermediate sum for the present cycle

$IS_{(n-1)}$ equals the intermediate sum from the last cycle

C1 Intermediate sum weighting coefficient

C2 Residual weighting coefficient

RES_n equals the residual between the measured (raw) and smoothed predicted position value $(X_n - \hat{X}P_n)$ of the present cycle

C2 is computed by the following equation:

$$C2 = 1.0/CT \qquad (3)$$

where CT is equal to the data sample count. The value C1 is then obtained from the following:

$$C1 = 1.0 - C2 \tag{4}$$

It can be shown that the results obtained from equation (2) are equal to the sample variance results of equation (1) for all values of n equal to CT and when the position estimate $\hat{X}_{Pn}$ approximates the expected value (μ). It should be noted that when systematic errors are introduced into the system, the Intermediate Sum is not representative of the estimated variance, but the results still provide an index of overall system performance.

As the sample size increases, the effect of the residual measurement on the Intermediate Sum becomes smaller and smaller. Under this condition, if the residuals start to increase, the response of the Intermediate Sum to this increase would be very slow. An increase in the residual measurement is indicative of an increase in random errors or a change in systematic errors. The responsive characteristics of the Intermediate Sum can be established by setting the weighting coefficient C2 in equation (2) to a fixed value after a specific sampling period. The smaller the C2 value is set, the closer the Intermediate Sum follows the sample variance. Therefore, if the value of C2 is increased, the Intermediate Sum tends to be influenced to a larger extent by the residual squared value.

The next step in the source selection process is to attach a Figure of Merit to each radar source. The

Figure of Merit for each radar source component is computed using the following equation:

$$FM_n = IS_n * A1 \quad (5)$$

where:

FM_n	is the Figure of Merit associated with a particular radar source component
IS_n	is the Intermediate Sum of that particular radar source component
A1	is the weighting coefficient for the particular source

The weighting coefficient is computed from the following:

$$A1 = \frac{LT}{CT} \quad (6)$$

where:

CT	is a counter which is increased by one count each data cycle up to a limit set by the response characteristic desired for the particular source considered
LT	is the limit of the CT counter

It can be seen from equation (5) that the Figure of Merit is equal to the Intermediate Sum when CT is equal to LT. Therefore, during initial acquisition and tracking, the Figure of Merit is much higher than the Intermediate Sum. As more data are obtained, the Figure

of Merit is reduced. This essentially increases the confidence in the data being obtained from the particular tracking source. Since the position data are made up of three components (x,y,z) a Figure of Merit is computed for each component. This is of particular importance, since the flight safety function is highly dependent on directional considerations.

Following individual component Figure of Merit computation, the Total Figure of Merit for a particular source is obtained from the following equation:

$$TFM = B1 * FM(x) + B2 * FM(y) + B3 * FM(z) \qquad (7)$$

where:

TFM is the Total Figure of Merit for the source under evaluation

FM(x), FM(y), FM(z) are the individual component Figures of Merit for the source under consideration

B1, B2, B3 are component weighting factors

The component weighting factors, B1, B2, and B3, scale the Figure of Merit contribution of each component in accordance with its relative importance to the flight safety function. It should be noted that data from each radar source are weighted with the same set of coefficients during a mission.

Finally, the Total Figure of Merit for each source is checked to determine which source data should be used for impact computation on a given cycle. Selection of radar source is based on the minimum Total Figure of Merit of all sources available. If the Total Figure of Merit for two or more sources is nearly the same and varies slightly from cycle to cycle, rapid switching of source data could be experienced. This rapid switching will not normally improve the quality of the IIP data. Therefore, once a particular source has been selected automatically for use in the IIP computation, a new source should not be selected until its Total Figure of Merit is lower than the original source select Total Figure of Merit biased by a predetermined amount. The bias value selected will then control the switching frequency, if two or more sources have Total Figure of Merit values with approximately the same magnitude.

4.7 Armament Development and Test Center (ADTC)

4.7.1 Existing Techniques

Presently, no real-time data combination is performed. ADTC tracking radars are located at widely separated sites. The types of missions and flight profiles normally flown do not have sufficient geometrical relationships to tracking site locations to make data combination worthwhile in the safety solution. Since ADTC instrumentation complexes may have more than one radar active on a given test, automatic data source selection criteria is used.

4.7.1.1 Method

ADTC has the option of utilizing either vacuum or ballistic-drag impact prediction models in real time. Due to the premium of time and core storage for the ballistic case compared to the straight forward vacuum solution, two different techniques are used for automatic source select.

4.7.1.1.2 Vacuum Impact Predictor

For missions supported by vacuum impact prediction, the source selection scheme is based on an estimate of the impact point standard deviation for each sensor. The variance in impact point is computed as follows:

$$\sigma_n = \left(\frac{\delta N^2}{\delta X}\right)\sigma_X^2 + \left(\frac{\delta N}{\delta Y}\right)^2 \sigma_Y^{\,2} + \left(\frac{\delta N}{\delta Z}\right)^2 \sigma_Z^{\,2}$$

$$+ \left(\frac{\delta N}{\delta \dot{X}}\right)^2 \sigma_{\dot{X}}^{\,2} + \left(\frac{\delta N}{\delta \dot{Y}}\right)^2 \sigma_{\dot{Y}}^{\,2} + \left(\frac{\delta N}{\delta \dot{Z}}\right)^2 \sigma_{\dot{Z}}^{\,2}$$

where X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$, = state vectors

$n = \phi$, latitude; λ, longitude, and

partial derivatives are computed from closed form vacuum impact equations, and σ_X, etc., are output from filter.

The standard deviation of the impact point is estimated from $S = R_{c\phi} C$ where $R_{c\phi}$ = radius of earth's curvature at geodetic latitude ϕ

$$C = \cos^{-1}\left[\cos \frac{(R_{c\phi} \cdot \mathrm{Cos}\ \theta \cdot \sigma_\lambda)}{R_{c\phi}} \cos \sigma_\phi\right]$$

with $R_{C\phi}$ = radius of earth at geodetic latitude ϕ

and θ = geocentric latitude.

The criteria for best data source is the sensor with the minimum value of S. However, to avoid rapid switching when two or more sensors have nearly equal values, the following additional test must be satisfied:

$$\frac{S_L}{S_N} < .95$$

or, the value of the unselected source, S_L, must be 5 percent smaller than that of the selected source, S_N, before switching occurs.

4.7.1.1.3 Ballistic Impact Predictor

Since much computer cycle time is required for the *integration* of the ballistic impact predictor model, a faster and simpler technique is used for source selection. In this case a statistic is formed for each sensor as follows:

$$\nu = \frac{\sigma_X{}^2 + \sigma_Y{}^2 + \sigma_Z{}^2}{K}$$

where σ_X, σ_Y, σ_Z, = estimates of variance output from filter,

and K = degrees of freedom (number of points smoothing -3).

The sensor with the smaller value of ν is selected as best. The same criteria for switching as outlined above is used to avoid rapid selection and deselection when values from two or more sensors are nearly equal.

4.7.2 Planned Future Actions

Present ADTC source selection problems are rather trivial. The real-time system will presently accept only three data sensors. The problem that most often occurs is one of when to hand over track between widely separated tracking sites, rather than determining which sensor is best. However, ADTC is in the planning stages of a major real-time system expansion and modernization which will effect all areas of mission control. Available data sources will be expanded from three to eighteen. Conversion to computer driven CRT's displaying debris patterns, and the implementation of automatic flight termination capability, will require the development of more sensitive and adaptive filtering and source selection techniques.